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BALLOONING METHODOLOGY: EQUATIONS FOR ESTIMATING MASSES OF STICKY-TRAPPED SPIDERS

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ABSTRACT

Most empirical studies of spider ballooning use sticky traps to sample the aeronaut fauna. Once the animals are removed from the adhesive and passed through solvents into preservative, biologically meaningful masses cannot be determined directly. We use simple linear regressions to describe relationships between live masses of wild-caught animals and a volume estimate which treats the spider as a cylindrical solid with diameter equal to the mean of greatest carapace and abdomen width and height equal to total length. Of regressions for six families studied in detail, the slope for tetragnathids differs significantly from those for all but one of the other five. Pair-wise comparisons of slopes for the five non-tetragnathid families show no statistically significant differences. We therefore present two linear regression equations, one for tetragnathids and other similar-shaped spiders, and the other for "typical" (all other) spiders. Limited data from one species each of pisaurid and linyphiid are statistically indistinguishable from the "typical" regression but highly significantly different from the tetragnathid regression, lending added support to a dichotomy in shape between tetragnathids and other spiders. Simple linear regressions of mass on the volume estimate tend to explain more of the variation in mass than traditional power functions of mass on measurements of single body dimensions.

INTRODUCTION

Ballooning (aerial dispersal) in spiders is a dramatic and widespread phenomenon. Although a fair amount is known about the taxonomic composition, seasonal occurrence, and reproductive maturity of aeronauts, nothing has been published on their mass frequency distributions. The masses of ballooning spiders are of fundamental interest since one wonders how massive a flightless animal can be and still be passively carried by the wind. The masses of ballooners also have profound biogeographic implications, since, within a species, larger (more massive) animals will have higher reproductive value and hence higher colonizing potential (MacArthur and Wilson 1967). By the same token certain species may have very low colonizing potential because they are larger as adults and can only balloon at very early stages when reproductive value is low.

The most desirable way to sample the aeronaut fauna would be with continuously operating suction traps (Taylor 1974), which can be calibrated to give absolute estimates of aerial density. However they are expensive and require the availability of electricity. This has led most workers to use sticky traps of one form or another (Duffey 1956, van Wingerden and Vugts 1974, Yeargan 1975). Of course after a spider has been removed from the trap and placed in one or more solvents to remove the adhesive and preserve it, direct measurements of mass are meaningless. The present study was undertaken to develop methods to estimate the live masses of spiders collected from sticky traps.

Live spiders were collected from late may to late July in a variety of habitats in North Central Missouri, viz., the Tucker Preserve (native tall grass prairie), The University of Missouri Ashland Wildlife Area (mixed hardwood forest understory and woodland clearings), The University of Missouri, Columbia campus (ornamental shrubs), the U.S. Department of Agriculture, Biological Control of Insects Research Laboratory study plot (alfalfa), and the University of Missouri South Farms (soybeans). With the exception of Tucker Prairie, which is in Callaway County, all localities are in Boone County. Spiders were separated from vegetation by sweeping, beating or aspiration, dumped in a sleeve cage or on a drop cloth for sorting and placed in individual shell vials. The live spiders were transported in a styrofoam chest to the laboratory where they were weighted to the nearest 0.1 mg in a tared gelatin capsule on a Mettler AE 160 electronic balance. After weighing they were killed and preserved in 70% ethanol.

A few days later the following three measurements were made on each animal to the nearest 0.05 mm, using a wild M5 stereo microscope with ocular micrometer at 120 x magnification: total length, greatest width of cephalothorax, and greatest width of abdomen. An estimate of each spider's volume was obtained by treating it as a cylindrical solid having radius equal to half the mean of the two width measurements and height equal to total length, i.e.

$$\text{Volume} = (\text{Total length})\,\pi\,[(\text{Width Abd} + \text{Width Ceph})/4]^2$$

Assuming further that the density of material is homogeneous throughout a spider's body and fixed regardless of absolute mass, we expected to find a linear relationship between the measured mass and estimated volume.

Because spiders are not perfectly cylindrical we expected families to show different mass-volume relationships. In particular we expected to find significant differences among the tetragnathids, which are most nearly cylindrical, the thomisids (in the broad sense, including philodromids) which tend to be flattened dorsoventrally, and most other families, whose members can be idealized as two more or less overlapping subspherical pieces. Only animals less than 20 mg in mass were studied because more massive animal were not expected to be common ballooners.

RESULTS AND DISCUSSION

The raw data for eight families are presented in Fig. 1. Sample sizes and least squares regression parameters are presented in Table 1. All are highly significant ($p < 0.01$). The data were subjected to Bartlett's Test for Homogeneity of

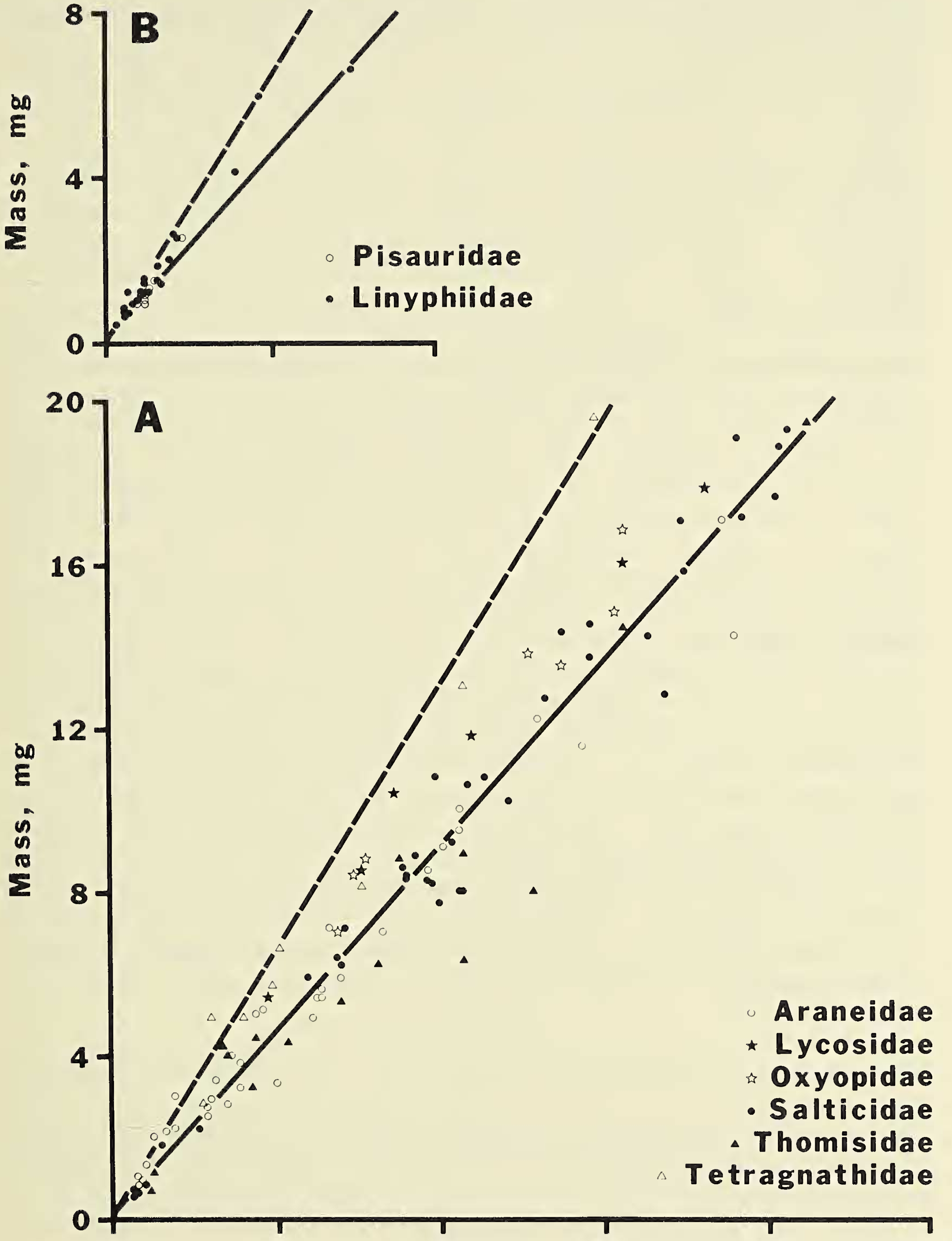

Fig. 1.—Raw data and regressions for mass-volume relationships: A, Tetragnathidae (dashed line) and combined data for the remaining five families (solid line); B, Raw data for the Lyniphiidae and Pisauridae (lines in Fig. 1A).

Table 1.—Individual regression parameters. V = linear regression of mass on volume, C = power curve of mass versus cephalothroax width, TL = power curve of mass versus total length, N = sample size, a = regression intercept, b = regression slope, R^2 = coefficient of determination.

Family	*N*	a_v	b_v	R^2_v	R^2_c	R^2_{TL}
Lycosidae	6	1.69	1.14	0.99	0.30	0.99
Salticide	37	−0.01	1.14	0.97	0.91	0.76
Araneidae	36	0.55	1.02	0.97	0.84	0.89
Oxyopidae	7	1.14	1.17	0.97	0.16	0.58
Tetragnathide	8	0.31	1.61	0.98	0.74	0.90
Thomisidae	15	−0.01	1.05	0.92	0.92	0.97
Pisauride	8	−0.33	1.57	0.97	0.75	0.82
Linyphiide	28	0.26	1.20	0.94	0.52	0.92

Variance (Sokal and Rohlf 1969) and found to be significantly heterogeneous ($X^2_7 = 62.159$, $p < 0.001$) prohibiting overall parametric analysis. Inspection of Fig. 1 suggests that this result was due to the smaller range of variation exhibited by the pisaurids (comprising eight *Pisaurina* spiderling) and the linyphiids (comprising only individuals of the single species *Frontinella pyramitela*). When only the remaining six families data are subjected to Bartlett's Test there is no evidence of significant heterogeneity of variances ($X_5 = 3.848$, $p > 0.5$), permitting an analysis of Covariance (Snedecor and Cochran 1967) to test the hypothesis of no differences among mass-volume regressions. This revealed highly significant differences among slopes ($F_{5,\ 97} = 3.339$, $p < 0.01$). In order to determine where these differences lie, all possible pair-wise t-tests on slopes were performed. The method of Bonferroni (Morrison 1983) was used to derive the critical value for an overall error rate error less than 0.05. Results of these tests are presented in Table 2. As expected the tetragnathids differ significantly from most of the other families (the sole exception was the Oxyopidae, with $0.05 < p < 0.10$). However the thomisids do not differ significantly from the other families, owing perhaps to their higher variance (See Fig. 1 and the R^2's in Table 1), i.e. to their failure to conform as well to the assumptions of the mass-volume model. Given these data, we suggest that workers wishing to estimate the masses of preserved spiders may do so by using the cylindrical approximation to volume as the independent variable for one of two regressions. If the animal is a tetragnathid, use:

$$\text{Mass(in mg)} = 1.61\ (\text{volume in mm}^3) + 0.31 \qquad \text{(see Table 1 and Fig 1A)}$$

(We predict that other patently cylindrical spiders, such as *Tibellus* and *Larinia* spp. which were not collected in this study, will also fit this model). The following

Table 2.—t values and levels of significance for pair-wise t-tests on slopes. Levels of significance are coded as n.s. (>0.1) and * (<0.05). See text for explanation.

	Salticidae	Araneidae	Oxyopidae	Tetragnathide	Thomisidae
Lycosidae	−0.034, n.s.	1.444, n.s.	0.292, n.s.	−3.760, *	0.544, n.s.
Salticidae	—	2.615, n.s.	−0.244, n.s.	4.363, *	1.213, n.s.
Araneidae	—	—	−1.542, n.s.	6.710, *	−0.428, n.s.
Oxyopidae	—	—	—	−3.014, n.s.	0.6541, n.s.
Tetragnathidae	—	—	—	—	3.450, *
Thomisidae	—	—	—	—	—

overall regression for all other families, which could be considered as having "typical" shape, was derived by combining the data from the non-tetragnathid families in Fig. 1A:

$$\text{Mass (in mg)} = 1.12 \text{ (volume in mm}^3\text{)} + 0.23$$

The utility of these equations, and particularly the assumption that all spiders besides tetragnathids and their look-alikes are essentially the same shape and homogeneous with respect to density, will be determined with time. As a partial test we offer the "goodness of fit" of the pisaurid and linyphiid data, which have lower variance than the other six families but show an obvious linear relationship between mass and volume (Fig. 1B), to the two regressions. Lines of least squares are fit such that half the points lie above and half lie below the line. If pisaurids and linyphiids are shaped like "typical" spiders, then the proportion of points lying above (and below) the "typical" regression line should not differ significantly from 0.5, whereas the proportions of points and below the tetragnathid line *should* differ significantly from 0.5. The numbers of points on each side of both lines for both regressions in each family are given in Table 3. The proportions of points above or below the "typical" regression line do not differ significantly form 0.5 using the Binomial Test (Siegel 1956) ($p > 0.29$ and $p > 0.34$, pisaurids and linyphiids, respectively) but are highly significantly different from 0.5 for the tetragnathid regression ($p < 0.008$ and $p < 0.0001$, respectively), supporting our contention that the linyphiids and pisaurids have a "typical" spider shape different from that of tetragnathids.

The most commonly used index of size for spiders has been cephalothorax width. It is a logical index of instar, since as a single sclerotized plate the carapace is not apt to change its dimensions very much during the instar (see Hagstrum 1971 and references cited therein). On the other hand it cannot be expected to be a good indicator of mass, which can vary widely within an instar due to nutritional and reproductive state. Breymeyer (1967) used simple linear regression and Sage (1982) used step-wise linear regression to derive a relationship between mass and total length. Rogers et al. (1977) found that a power function gave the best fit for the total length vs. mass relationship for spiders. In Table 1 we present the coefficients of determination for the simple linear regressions of mass on volume (V) and for the power curves of mass on cephalothorax width (C) and mass on total length (TL), for each family. The simple linear regression of mass on volume is clearly a better description of the relationship than either power curve in most cases. An alternative approach is to take the oven-dried weight of the spider after removal from the trap and apply a conversion factor (S. E. Riechert, pers. commun.). This is less time-consuming but not useful if one wishes to save the specimen for identification.

Table 3.—Numbers of pisaurid and linyphiid points lying above (+) and below (−) calculated overall and tetragnathid regression lines.

	Overall Regression		Tetragnathid Regression	
	+	−	+	−
Pisauridae	2	6	0	8
Linyphiidae	16	12	1	27

As Table I shows, an estimate of volume will tend to be a more accurate predictor of mass than a single linear measurement. The method presented here is tedious but accurate. A logical extension of our technique would be to determine the frontal sectional area of the image of the spider by projecting the surface of a digitizing tablet into the microscope field with a drawing tube. This area estimate could then be rotated by an appropriate algorithm in a microcomputer to produce a spider-shaped, rather than a cylindrical, estimate of the volume.

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